PERFORMANCE OF MULTILAYER COATED TOOL IN DRY MACHINING OF AISI 316 AUSTENITIC STAINLESS STEEL

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE DEGREE OF

BACHELOR OF TECHNOLOGY

IN

MECHANICAL ENGINEERING

BY

AJIT SORENG

107ME007

UNDER THE GUIDANCE OF

Dr. S.GANGOPADHYAY

DEPARTMENT OF MECHANICAL ENGINEERING

NATIONAL INSTITUE OF TECHNOLOGY ROURKELA

ROURKELA-769008

National Institute of Technology

Rourkela

Certificate of Approval

This is to certify that the thesis entitled "**PERFORMANCE OF MULTILAYER COATED TOOL IN DRY MACHINING OF AISI 316 AUSTENITIC STAINLESS STEEL**" submitted by Sri Ajit Soreng has been carried out under my supervision in partial fulfilment of the requirements for the Degree of Bachelor of Technology (B. Tech.) in Mechanical Engineering at National Institute of Technology, NIT Rourkela, and this work has not been submitted elsewhere before for any other academic degree/diploma.

However, experimental part reported here has been jointly conducted by Sri Ajit Soreng. and Sanjib Kumar Hansda

Dr. S.Gangopadhyay
Department of Mechanical Engineering
National Institute of Technology, Rourkela

Rourkela-769008

Date: 11-05-2011

ACKNOWLEDGEMENT

I wish to express my profound gratitude and indebtedness to ***Dr. Soumya Gangopadhyay,*** Assistant Professor, Department of Mechanical Engineering, National Institute of Technology, Rourkela, for introducing the present topic and for his inspiring guidance, constructive criticism and valuable suggestion throughout this project work.

I am thankful to ***Prof. Ranjit Kumar Sahoo***, Head, Department of Mechanical Engineering, National Institute of Technology, Rourkela, for his constant support and encouragement. I am also grateful to ***Prof. Chandan Kumar Biswas***, Department of Mechanical Engineering, National Institute of Technology, Rourkela, for his help and support in providing us valuable inputs and permitting us to use the Production Engineering Laboratory for the experiments. I am also very thankful to ***Prof. S.K.Sahu*** for providing some useful research facility for carrying out a part of this project work.

I would also like to thank ***Mr. Kunal Nayek***, Staff Member of the Production Engineering Laboratory and ***Sri Shailesh Debangan***, Ph. D. Scholar of Production Engineering specialization and ***Sri Biranchi Narayan Sahoo***, M.Tech Student for their assistance and help in carrying out experiments. Last but not least, my sincere thanks to all our friends who have patiently extended all sorts of help for accomplishing this undertaking.

11th MAY 2011

AJIT SORENG

ROLL NO: 107ME007

CONTENTS

ABSTRACT

The recent advance in coating for cutting tool has significantly improved the machining performance in terms of tool life, machined surface quality and productivity. Multilayer coating synergize the advantage of different coating materials in the layered structure and has particular edge over monolayer coated tool. Austenitic stainless steel is one of the most important grades of stainless steel as it has a variety of engineering applications particularly when resistance to corrosion is a primary requirement. However, low thermal conductivity and work hardening characteristics have made it difficult to machine with conventional cutting tools under normal operating condition. Therefore in the present study, attempt was made to study the machinabilty of AISI 316 grade austenitic stainless steel with a commercially available multilayer coated cemented carbide turning insert. The multilayer coating consists of TiN-TiCN-Al_2O_3-ZrCN coating. The substrate and multilayer coating composition has excellent combination of hardness and toughness and the top coat of ZrCN has auto friction property. In the present study, the effect of cutting speed was studied on the dry machining performance of AISI 316 grade austenitic stainless steel in terms of tool wear(average flank wear) and chip characteristics(types & colour of chip, macro morphology and chip thickness). The study clearly indicates as the cutting speed increased from 100 to 200 m/min average flank wear increased for a particular machining duration. Consequently, tool life was also found to be maximum for V_c = 100 m/min while rapid progression of tool wear was observed for dry machining of V_c = 200 m/min. the increase in cutting speed also results in decrease in chip thickness and chip radius. Therefore the current study demonstrated the potential of multilayer coated cemented carbide insert in dry machining of AISI 316 austenitic stainless steel.

CHAPTER 1

INTRODUCTION:

There are different types of cutting tools used for machining such as high speed steel (HSS), Cemented carbide, Cermets, Ceramics, Cubic boron nitride, Diamond.

High speed steel (HSS) is a high carbon ferrous alloy consisting of W, Mo, Cr, V, and Co. HSS is usually available in cast, wrought and sintered (obtained by using powder metallurgy technique) form. It possesses considerable room temperature hardness in the range of 800-900 HV (above HRC 60) but starts to soften at around 600 ^{o}C, and the hardness falls to 150-180 HV at 700 $^{\circ}$C. HSS is inexpensive compared to other tool materials, is easily shaped, and has excellent fracture toughness, and fatigue resistance. The limited wear resistance and chemical stability of HSS makes it suitable for use only at limited cutting velocities of 30-50 m/min. HSS is very commonly used for geometrically complex rotary cutting tools such as drills, reamers, taps, and end-mills, as well as for broaches. High speed steels are broadly classified as T-type steels which have tungsten as the dominant alloying element, and M-type steels in which the primary alloying element is molybdenum. M-types are more widely used for rotary tooling, especially drills, milling cutters, and taps. The submicron HSS tool materials can be used for machining aluminium and other soft materials at very high speeds using a high positive rake angle tool thus reducing cutting forces significantly.

Alloying composition of common high speed steel grades (by %wt)

Grade	C	Cr	Mo	W	V	Co	Mn	Si
T1	0.65-0.80	3.75-4.00	-	17.25-18.75	0.9-1.3	-	0.1-0.4	0.2-0.4
M2	0.95	4.2	5.0	6.0	2.0	-	-	-
M7	1.00	3.8	8.7	1.6	2.0	-	-	-
M35	0.94	4.1	5.0	6.0	2.0	5.0	-	-
M42	1.10	3.8	9.5	1.5	1.2	8.0	-	-

Cemented carbide is a relatively modern cutting tool material manufactured by mixing, compacting and sintering primarily tungsten carbide (WC) and cobalt (Co) powders. Co acts as a binder for the hard WC grains. Cemented carbide possesses high transverse rupture strength, high fatigue and compressive strength, and high hot hardness. The carbide tool materials are chemically more stable, have high stiffness and exhibit lower friction, and operate at higher cutting velocities than HSS tools. They have strong metallic characteristics having good electrical and thermal conductivity. But carbide tools are more brittle and more expensive than HSS. As per ISO, cemented carbides are classified into three grades; P, M and K. P grade carbides, sometimes called mixed carbides, consist of TiC, TaC and NbC in addition to WC and Co. They are generally recommended for machining steel. M grade carbides are alloyed WC grades generally with less amount of TiC than the corresponding P series, and have wider application in machining austenitic stainless steel, manganese steel as well as steel castings, Ni-base superalloys, malleable and spherodised cast iron etc. K grade carbides are straight tungsten carbide grades with no alloying carbides. They are used for machining grey cast iron, nonferrous metals, and nonmetallic materials. Each grade within a group is assigned a number to represent its position from maximum hardness to maximum toughness (higher the number, tougher the tool). P grades are rated from P01 to P50, M grades from M10 to M40, and K grades from K01 to K40. The performance of carbide cutting tool is dependent on the percentage of Co and grain size of carbide(s).

Cermets are ceramic materials in a metal binder. They consist of TiC, TiN, or TiCN hard particles held together by a softer binder alloy of Co and/or Ni, Mo. Some of the cermets also include hard phases of Mo_2C, WC, and TaC. Cermets are less susceptible to diffusion wear than WC, and have more favourable frictional characteristics. However, they have a lower resistance to fracture, lower thermal conductivity and a higher thermal expansion coefficient than WC, and are more feed sensitive. Cermet cutting tools are suitable for the machining of steels, cast irons, cast steels and nonferrous free-machining alloys. They are capable of operating at higher cutting velocities than cemented carbides thus allowing better surface finish.

Ceramics are inorganic, non-metallic materials that are subjected to high temperature during synthesis or use. They retain excellent hardness and stiffness at temperature greater than 1000 °C, and do not react chemically with most work materials at these temperatures. The inadequate fracture toughness of ceramic tools makes them susceptible to mechanical and thermal shock during machining. There are two main categories of commercially available ceramic tools:

- Alumina-based ceramics comprising of pure oxide, mixed oxides, and silicon carbide (SiC) whisker reinforced alumina ceramics.
- Silicon nitride-based ceramics.

Cubic boron nitride (CBN) is the hardest tool material available after diamond. For cutting tool, cBN is manufactured from hexagonal boron nitride crystals under high temperature (1200 $^{\circ}$C-1500 $^{\circ}$C) and pressure (4-6 GPa) using solvent catalyst typically made from alkali and alkaline earth metal hydride. Their high temperature stability up to around 1400 $^{\circ}$C helps in achieving high material removal rate (MRR) as well as precision machining imparting excellent surface integrity to the products. The cBN has a high thermal conductivity and low thermal expansion coefficient, which makes it less sensitive to thermal shock than ceramics. Also, their fracture toughness falls between that of WC and ceramics. They are used for machining hardened steel at higher cutting velocities of 200 – 500 m/min. For machining Ni-based superalloys, the cutting velocity can be as high as 240 m/min. The limitations of cBN include inability to machine low carbon steel at very high cutting velocities, and its very high cost.

Diamond, the hardest of all tool materials, exhibits excellent wear resistance, holds an extremely sharp edge, generates little friction in the cut, and has good thermal conductivity. These properties contribute to long life of diamond tools in high speed machining of soft, nonferrous materials (aluminium, copper, magnesium etc.), Al-Si alloys, advanced composites, superalloys, and nonmetallic materials. But, diamond is not recommended for ferrous materials or hard metals because of the high solubility of diamond (carbon) in these materials. Diamond tools are available in single crystal and polycrystalline form.

Coated tool

Need of coating

The required properties of cutting tool material at the surface and in the bulk are different and conflicting. The surface of the tool needs to be hard, abrasion resistant, chemically inert, having low thermal conductivity, and having low coefficient of friction. The bulk of the tool should be tough, shock-resistant, having high thermal conductivity, and strong to resist high temperature plastic deformation to retain form and geometry. This combination of properties can be achieved by depositing a thin layer (typically 2-10 μm) of coating of suitable material over the surface of the tool. Coatings act as diffusion barrier between the tool and the sliding chip, they increase wear resistance of the tool, prevent chemical reactions between the tool and work material, reduce built-up edge formation, decrease friction between the tool and chip, and prevent deformation of the cutting edge due to excessive heating. Coated tools, therefore, can be used at higher cutting velocities and provide longer tool lives than uncoated tools. Recent advances in tool coating have made it an attractive choice for environment-friendly and cost effective dry machining.

Types of coatings

- **Conventional hard coatings**

The commonly used hard coatings for cutting tool applications include TiC, TiN, TiCN, Al_2O_3, TiAlN, AlON, HfN etc. All these coatings exhibit very low wettability against ferrous materials. TiC was the first hard material to be deposited over cemented carbide tool. Later, TiN proved to be a better diffusion resistant material and therefore more suitable candidate for combating crater wear. However, TiC is better in resisting flank wear owing to higher abrasive wear resistance. TiCN offers some kind of balanced properties between TiC and

TiN. Al_2O_3 provides chemically stable layer between chip and tool especially at higher temperatures. TiAlN is relatively new development to the family of hard coating and is of particular importance in metal cutting because of its higher hardness (around 35 GPa) and oxidation resistance at high temperature. a-C:H diamond like carbon (DLC) coating owing to its high hardness combined with superior anti-sticking property has also recently found its application as a coating material for cutting tools.

- **Multilayer coatings**

These coatings consist of alternate layers of different materials, deposited on top of another, and also forming between themselves transitional layers. Such multilayer structure allows stronger interface as well as dense and compact microstructure. Another significance of multilayer coating architecture is the synergistic effects of different components of the coating system. One or more of intermediate layer(s) ensure graduation of properties, and the outermost layer ensures good tribological properties. Some of the examples of multilayer coatings are TiC/TiCN/TiN, TiC/TiN/Al_2O_3, TiN/Al_2O_3/TiAlN, TiC/TiCN/TiN/Al_2O_3 (from interface to top layer) etc.

- **Multicomponent coatings**

In muticomponent metal nitride coatings the sublattice of one metallic element is partially filled by one or more metallic elements, similar to substitutional type solutions. The properties of the coating, therefore, can be tailored according to requirement in a specific application. Improved film-substrate adhesion combined with high film hardness and better oxidation resistance at elevated temperature is some of the important properties of multicomponent coatings that make them suitable for metal cutting application. The examples of recently developed muticomponent coatings include TiAIN, TiSiN, TiCrN, TiZrN, TiVN, AlCrN, CrTiAlN, TiAlSiN, AlCrSiN, TiAlCrYN etc.

- **Superlattice coatings**

Two coatings with the similar crystal structure and lattice constant are deposited alternately with the period of different layers typically in the range of 5-15 nm. This results in a coating with increased lattice strain and hardness. The typical examples of superlattice coatings include TiN/CrN, CrN/NbN, TiN/NbN, TiN/AlN, TiN/VN, CrN/AlN etc

- **Superhard coatings**

Diamond and cBN are the most popular members of the family of superhard coatings used for cutting tools. In addition to high hardness superhard materials usually possess some other excellent properties such as high thermal conductivity, oxidation resistance, chemical stability and low coefficient of friction. Diamond coatings with hardness in the range of 70-100 GPa are commonly synthesised using hot filament CVD process. However, high solubility of carbon in iron and other metals restrict the application of diamond coated tools to machining of aluminium alloys, ceramics, glass, wood etc. The cBN coatings are typically deposited by ion assisted PVD process. The challenge with PVD cBN films is to produce a thick, well adherent coating that can survive in the adverse environment during machining. Some other examples of superhard coatings include Si_3N_4, CN_x, BC_xN, Si-C-N, Ti-B-C-N possessing hardness in excess of 40 GPa. However, extensive research is being carried out to study the feasibility of their application in metal cutting.

- **Soft coatings**

Machining of sticky materials like alumnium and titanium alloys has been a major problem particularly when good surface finish, high productivity, and long tool life are concerned. Even use of conventional hard coatings like TiC, TiN, TiAlN etc. cannot yield satisfactory performance. To overcome this difficulty a new family of coating has been conceptualised. They are soft coating or solid lubricant coating like MoS_2, WS_2, graphite owing to the superior anti-friction property compared to conventional hard coatings. However, some of the major limitations of such coatings like poor abrasion, humidity and oxidation resistance restrict their use mainly to low speed machining operation like milling and drilling.

- **Composite coatings**

In composite coating, a small amount of metal and/or compound is impregnated into the monolayer homogeneous coating material with a view to either augment some of the existing properties or to impart some additional chrematistics or both. For example, the strength, adhesion and humidity resistance of pure MoS_2 coating can be improved by incorporation of different metals like Au, Ti, Mo, W etc. into soft matrix of MoS_2. Some of other examples of wear resistance composite coatings include Al/Al_2O_3, Ti/TiN, Cr/TiN, Al/TiN etc. The composite coating may or may not have layered structure depending on deposition condition and crystal structure of individual materials

STAINLESS STEEL

Stainless steel contain a high proportion of chromium generally in excess of 11%. When an alloy of steel contains more than approximately 10 ½ % chromium it can be classified as a stainless steel. This is because chromium has a high affinity for oxygen and forms a stable oxide film on the surface of the steel. This film is resistant to further chemical or physical or chemical change. High strength, high work hardening rate and low thermal conductivity austenitic stainless steel, it is generally regarded as difficulty to machining. Whereas the corrosion resistance of these materials is excellent, their hardness and wear resistance are relatively low. Problems such as poor surface finish and high tool wear are common. In addition, they bond very strongly to the cutting tool during machining and when the chip is broken away, it may bring with it a fragment of the tool. Particularly when cutting with uncoated cemented carbide tool. So, this problem can be expel by using coating materials. Stainless steel are classified into four categories depending on their primary constituent of the material.

Ferritic stainless steel: Ferritic stainless steels are straight-chromium 400 series metals that cannot be hardened by heat treatment and only moderately hardened by cold working. They are magnetic, have good ductility and resistant against corrosion and oxidation This group contains minimum of 17% chrome and carbon in the range 0.08-0.2%. The increase in chromium gives increased corrosion resistance at high temperature. Ferritic stainless steel are alloyed primarily with chromium ,Mo, Ti, . This type of stainless steel is ferromagnetic in nature. This steel has relatively good ductility and is usually used to make kitchen utensils

e.x., Type 430, 409, 434, 439, 442, and 446. Type 430 is a general- purpose ferritic stainless steel.

Application are:

- Automotive exhaust
- Automotive trims
- Computer floppy disk hubs

Martensitic stainless steel: This steel is called martensitic as it possesses a martensitic crystal structure in hardened condition. Chromium and carbon are the main contents of martensitic stainless steel. Martensitic stainless steels are straight chromium 400 series metals that can be hardened by heat treatment. They are magnetic , resist corrosion in mild environments and have fairly good ductility. This group contains a minimum of 12% chrome and maximum of 14% with carbon in the range of 0.08 – 0.2%. Martensitic alloys may contain carbon, Mo and Ni to increase strength. Increasing the nickel content increases the annealed hardness and also reduces machinability.

e.x., Type 410,416, 431,440, 440C, 403, 414

Application are :

- Surgical instruments
- Knives and blades
- Shafts and spindles

Austenitic stainless steel: 200 series of steels are stainless steels that contains chromium, nickel and manganese. 300 series austenitic steels are stainless steels that contains chromium and nickel. They can be hardened by cold working but not by heat treatment. In the annealed condition, all are essentially non magnetic; although some may become slighty magnetic by cold working. They have excellent corrosion resistance, usually good formability, and increased strength due to cold working. This group contains chromium in the range 17-25% and nickel in the range 8-20%. It contains nitrogen, carbon, and nickel or manganese in addition to chromium. Increasing carbon content , increases the work hardening rate and also decreases machinability. Carbon % in the range of 0.02-0.1%. This steel is called austenitic because it is made from austenitizing elements. Iron, nickel and chromium are the basic austenitizing constituents of this type of stainless steel.

e.x., Type 304, Type 316, Type 321, Type 347

Application are:

- Petrochemical industries
- Food processing industries
- Kitchen sinks
- Chemical plants

Duplex: This type of steel is used in chloride and sulphide environments and is least corrosive The structure of duplex stainless steels consists of a combination of ferritic and austenitic phases. This relatively new group has a balance of chromium , nickel, molybdenum and nitrogen to give a near equal mix of austenitic and ferritic. Duplex stainless steels have corrosion resistance properties that are equivalent to or better than austenitic stainless steels. Duplex stainless steels also have improved mechanical properties.

e.x., UNS S31 803 **:**composition is 0.03% max. carbon, 22% Cr , 5.5% Ni, 3% Mo and 0.15%N

UNS S32 304**:** Typical compostion is 0.03% max carbon, 23% Cr, 4% Ni, 0.1%N. Similar corrosion properties to type 316 but double the tensile properties.

UNS S32 750: composition is 0.03% max. carbon, 25% Cr , 7% Ni, 4 %Mo, and 0.28% N.

Applications are:

- Oil and gas explorations and off-shore rigs
- Chemical processing, transport and storage
- Pulp and paper manufacturing

TABLE1.1 Composition of different types of stainless steel.

SAE designation	% Cr	% Ni	% C	% Mn	% Si	% p	%S	%N	others
201	16–18	3.5–5.5	0.15	5.5–7.5	0.75	0.06	0.03	0.25	-
202	17–19	4–6	0.15	7.5–10.0	0.75	0.06	0.03	0.25	-
205	16.5–18	1–1.75	0.12–0.25	14–15.5	0.75	0.06	0.03	0.32–0.40	-
254	20	18	0.02 max	-	-	-	-	0.20	6 Mo; 0.75 Cu; "Super austenitic" ; All values nominal
301	16–18	6–8	0.15	2	0.75	0.045	0.03	-	-
302	17–19	8–10	0.15	2	0.75	0.045	0.03	0.1	-
302B	17–19	8–10	0.15	2	2.0–3.0	0.045	0.03	-	-
303	17–19	8–10	0.15	2	1	0.2	0.15 min	-	Mo 0.60 (optional)
303Se	17–19	8–10	0.15	2	1	0.2	0.06	-	0.15 Se min
304	18–20	8–10.50	0.08	2	0.75	0.045	0.03	0.1	-

304L	18–20	8–12	0.03	2	0.75	0.045	0.03	0.1	-
304Cu	17–19	8–10	0.08	2	0.75	0.045	0.03	-	3–4 Cu
304N	18–20	8–10.50	0.08	2	0.75	0.045	0.03	0.10–0.16	-
305	17–19	10.50–13	0.12	2	0.75	0.045	0.03	-	-
308	19–21	10–12	0.08	2	1	0.045	0.03	-	-
309	22–24	12–15	0.2	2	1	0.045	0.03	-	-
309S	22–24	12–15	0.08	2	1	0.045	0.03	-	-
310	24–26	19–22	0.25	2	1.5	0.045	0.03	-	-
310S	24–26	19–22	0.08	2	1.5	0.045	0.03	-	-
314	23–26	19–22	0.25	2	1.5–3.0	0.045	0.03	-	-
316	16–18	10–14	0.08	2	0.75	0.045	0.03	0.10	2.0–3.0 Mo
316L	16–18	10–14	0.03	2	0.75	0.045	0.03	0.10	2.0–3.0 Mo
316F	16–18	10–14	0.08	2	1	0.2	0.10 min	-	1.75–2.50 Mo
316N	16–18	10–14	0.08	2	0.75	0.045	0.03	0.10–0.16	2.0–3.0 Mo
317	18–20	11–15	0.08	2	0.75	0.045	0.03	0.10 max	3.0–4.0 Mo

317L	18–20	11–15	0.03	2	0.75	0.045	0.03	0.10 max	3.0–4.0 Mo
321	17–19	9–12	0.08	2	0.75	0.045	0.03	0.10	Ti 5(C+N)
329	23–28	2.5–5	0.08	2	0.75	0.04	0.03	-	1–2 Mo
330	17–20	34–37	0.08	2	0.75–1.50	0.04	0.03	-	-
347	17–19	9–13	0.08	2	0.75	0.045	0.030	-	Nb + Ta, 10 x C min, 1 max
348	17–19	9–13	0.08	2	0.75	0.045	0.030	-	Nb + Ta, 10 x C min, 1 max, but 0.10 Ta max; 0.20 Ca
384	15–17	17–19	0.08	2	1	0.045	0.03	-	-

SAE designation	% Cr	% Ni	% C	% Mn	% Si	% P	% S	% N	Other
405	11.5–14.5	-	0.08	1	1	0.04	0.03	-	0.1–0.3 Al, 0.60 max
409	10.5–11.75	0.05	0.08	1	1	0.045	0.03	-	Ti 6 x C, but 0.75 max
429	14–16	0.75	0.12	1	1	0.04	0.03	-	-
430	16–18	0.75	0.12	1	1	0.04	0.03	-	-
430F	16–18	-	0.12	1.25	1	0.06	0.15 min	-	0.60 Mo
430FSe	16–18	-	0.12	1.25	1	0.06	0.06	-	0.15 Se min
434	16–18	-	0.12	1	1	0.04	0.03	-	0.75–1.25 Mo
436	16–18	-	0.12	1	1	0.04	0.03	-	0.75–1.25 Mo; Nb+Ta 5 x C min, 0.70 max
442	18–23	-	0.2	1	1	0.04	0.03	-	-
446	23–27	0.25	0.2	1.5	1	0.04	0.03	-	-

SAE designation	% Cr	% Ni	% C	% Mn	% Si	% P	% S	% N	Other
403	11.5–13.0	0.60	0.15	1	0.5	0.04	0.03	-	-
410	11.5–13.5	0.75	0.15	1	1	0.04	0.03	-	-
414	11.5–13.5	1.25–2.50	0.15	1	1	0.04	0.03	-	-
416	12–14	-	0.15	1.25	1	0.06	0.15 min	-	0.060 Mo (optional)
416Se	12–14	-	0.15	1.25	1	0.06	0.06	-	0.15 Se min
420	12–14	-	0.15 min	1	1	0.04	0.03	-	-
420F	12–14	-	0.15 min	1.25	1	0.06	0.15 min	-	0.60 Mo
422	11.0–12.5	0.50–1.0	0.20–0.25	0.5–1.0	0.5	0.025	0.025	-	0.90–1.25 Mo; 0.20–0.30 V; 0.90–1.25 W
431	15–17	1.25–2.50	0.2	1	1	0.04	0.03	-	-
440A	16–18	-	0.60–0.75	1	1	0.04	0.03	-	0.75 Mo
440B	16–18	-	0.75–0.95	1	1	0.04	0.03	-	0.75 Mo
440C	16–18	-	0.95–1.20	1	1	0.04	0.03	-	0.75 Mo

SAE designation	% Cr	% Ni	% C	% Mn	% Si	% P	% S	% N	Other
501	4–6	-	0.10 min	1	1	0.04	0.03	-	0.40–0.65 Mo
502	4–6	-	0.1	1	1	0.04	0.03	-	0.40–0.65 Mo
2205[8]	22	5	0.03 max	-	-	-	-	0.15	3 Mo; All values nominal
2507[8]	25	7	0.03 max	-	-	-	-	0.28	4 Mo; All values nominal
630	15-17	3-5	0.07	1	1	0.04	0.03	-	Cu 3-5,

The work piece material used for present work was AISI 316 austenitic stainless steel. There are two types of austenitic stainless steel: 300-series and 200-series. Most stainless steel used around the world is of the 300-series type. Grade 316 is considered as the standard molybdenum bearing grade, second in importance to 304 grade amongst the austenitic stainless steels. The molybdenum gives 316 grade better overall corrosion resistant properties than Grade 304 grade, particularly higher resistance to pitting and crevice corrosion in chloride environments is seen. It also has excellent forming and welding characteristics. It is readily brake or roll formed into a variety of parts for the applications in industrial, architectural, and transportation fields. The main difference between 304 and 316 stainless steel is that 316 contains 2%-3% molybdenum and 304 has no molybdenum. The main difference between 304 and 316 stainless steel is that 316 contains 2%-3% molybdenum and 304 has no molybdenum. The "moly" is added to improve the corrosion resistance to chlorides.

TABLE 1.2 CHEMICAL COMPOSITION

AISI Grade	Chemical Composition(%)							
	C	**Si**	**Mn**	**P**	**S**	**Ni**	**Cr**	**Mo**
304	□0.08	□1.00	□2.00	□0.045	□0.030	8.00~10.50	18.00~20.00	-
316	□0.045	□1.00	□2.00	□0.045	□0.030	10.00~14.00	10.00~18.00	2.00~3.00

304 is a low carbon modification of 302 SST (which is the general purpose of austenitic or 18-8 SST) for restriction of carbide precipitation during welding. 304L is a lower carbon modification of 304 for further restriction of carbide precipitation during welding. Max carbon in 304 is 0.08 versus 0.15 in 302 and 0.03 in 304L. 304 has better welding characteristics and is less apt to intergranular corrosion. Often is used in welded or fabricated structures.

316 is more corrosion resistant than 302 and 304, with higher creep strength, primarily due to the higher Nickel content. 316L is again primarily used for welded construction. 316 has the same carbon content as 304 and 316L as 304L. 316 has superior corrosion resistance to salt water any many chemicals, excellent high-temperature tensile and creep characteristics.

CHAPTER 2

LITERATURE REVIEW

Machining characteristic of stainless steel

Austenitic stainless steel with properties like high strength, low thermal conductivity, high ductility and high work hardening tendency make them difficult to machine. Poor surface finish and high tool wear problems are common. Techniques have been developed to exploit the beneficial properties of a number of materials in a single application. One effective technique is the coating of thin layers of one or more highly wear resistant materials such as TiC, TIN, Ti(CN), Al_2O_3 and Ti(N,C,O) on tough and strong substrates such as conventional cemented carbides.

2.1 Effect of machining parameters on tool life

High work tendency, high ductility, low thermal conductivity and high strength of austenitic stainless steels make their machinability difficult. The influence of cutting speed on tool wear was investigated by Korkut et al. (2003) while machining 304 austenitic stainless steel using multilayer coated cemented carbide tool. The test were conducted at 120, 150 and 180 m/min at constant feed rate and depth of cut of 0.24mm/rev and 2.5 mm respectively, also correlation was made between tool wear and the chip obtained at three different cutting speed. It has been observed that the chip obtained at 120m/min had small chip curl radii and high chip thickness. With increasing cutting speed to 150 and 180 m/min the chip curl radii increases and the chip thickness decreases. From we can deduce that the thick chip with small curl radii at 120 m/min have less surface area and those with big chip curl radii and small thickness (i.e at 150 and 200m/min) due to which less efficient heat dissipation . Again, at

120 m/min tool chip contact length is more comparatively than 150 and 180m/min. As a result high chip temperature and long contact time on the rake face gave rise to thermal softening of the tool by conduction of heat from chip to the tool. Thus, reduction of wear resistance of tool takes place. So Tool wear decreases with increasing cutting speed.

According to agarwal et al. (1993), deep craters formed on the rake face of the coated tools during machining of three cast austenitic stainless steel having different composition It was mainly due to the rapid diffusion wear of the tools. TiN coating has failed to providing any barrier to such diffusion wear. As Ti, N, C are highly soluble in austenitic stainless steel. Thus tendency for the rapid tool-chip adhesion and rake crater wear on the coated carbide have been obtained during the machining of the austenitic stainless steel. During machining diffusion of carbon from the tool to the chip under surface have been observed.

According to Lin (2002), the effect of tool life while drilling stainless steel at high speed machining using a TiN coated tool with curved cutting edges were used. The cutting parameters being used for test to be carried out was cutting speed of 65, 75, and 85 m/min, feed rate of 0.05, 0.1, 0.15 and 0.2 mm/rev.the tool rejection criteria for the machining trials was maximum flank wear land of >0.8mm. It has been observed that tool life increased as the feed rate decreased.

2.2 Effect of machining parameters on surface roughness

According to Ciftci (2005) , the influence of cutting speed on the machined surface roughness were investigated, test were conducted on AISI 304 and AISI 316 austenitic stainless steel using two CVD multilayer coated cemented carbide tools i.e. TiC/TiCN/TiN and TiCN/TiC/Al_2o_3 at four different cutting speed (120, 150 180, and 210m/min) with feed rate and depth of cut constant at 0.16 mm/rev and 1mm respectively. It has been found that surface roughness values decreased until a minimum value was reached with increasing cutting speed and then increased with further increase in cutting speed. Higher surface roughness values were observed at 120 m/min cutting speed for both cutting tools and for both work piece material due to tendency to form BUE at lower cutting speed. But with increasing cutting speed up to 180 m/min, surface roughness values decreased due to decreasing BUE formation tendency with increasing cutting speed. Further, increase in cutting speed up to 210 m/min, the surface roughness values increases because of the increasing cutting tool nose wear.

Korkut et al. (2003) investigated on the influence of cutting speed on the surface roughness. The test were conducted on AISI 304 austenitic stainless steel at three cutting speed 120, 150 and 180 m/min at constant feed rate and depth of cut of 0.24 mm/rev and 2.5 mm respectively . the tool used were multilayer coated cemented carbide tool. It has been observed that surface roughness values were found to decrease with the increasing cutting speed which can be explained by presence of BUE at lower cutting speed and BUE formation decreases with increasing cutting speed.

According to selvaraj et al. (2010), dry turning test on cast duplex stainless steels using TiC and TiCN coated cemented carbide cutting tool at five different cutting speed 80, 100, 120,140 and 160 m/min and three different feed rates 0.04, 0.08 and 0.12 mm/rev with constant depth of cut 0.5mm was done and investigated the influence of cutting speed and feed rate on the machined surface roughness. It has been observed that with increasing cutting speed upto 100 m/min the surface roughness values decreases due to the decreasing built up edge formation up to 100 m/min. but with further increase in cutting speed upto 180 m/min surface roughness value increases due to the increasing cutting tool nose wear at higher speed. Moreover, the feed rate used were 0.04, 0.08 and 0.12 mm/rev shown a significant effect on surface roughness. It has been observed that surface roughness obtained at the feed rate of 0.04 mm/rev gave a minimum value. This is due to the widening in the area of contact and changes in the force per unit length, resulting in great distortion of sticky chip.

Later on, by orrego et al. (2010) depicted that feed rate shown a better effect on surface roughness than cutting speed. Surface finishing of AISI 304 stainless steel after tested by turning machining was mainly affected by the feed rate. The test was conducted for understanding the effect of the variation of feed rate and cutting speed in surface integrity while turning AISI 304 austenitic stainless steel using cemented carbide. Feed rate used were 0.15, 0.3 and 0.6 mm/rev and three cutting speed of 40, 80 and 120 m/min with constant depth of cut 1mm. It was seen that feed rate was the most influencing parameter affecting surface roughness values. The result depicted that surface roughness had a negligible variation with the cutting speed. With high feed rate of 0.6 mm/rev, it showed a highest value of surface roughness and with lowest feed rate showed a lowest surface roughness. From this it can be explain that with increasing feed rate, surface roughness value also increases. The flattest surface finishing obtained through roughness measurements was found for the cutting condition of 0.15 mm/rev and 120 m/min.

2.3 Effect of top coating on cutting forces,tool wear

The influence of cutting tool coating top layer on cutting force were investigated by ciftci(2005). While machining on AISI 304 and AISI 316 austenitic stainless steel using two CVD multilayer coated cemented carbide i.e. TiC/TiCN/TiN and TiCN/TiC/Al_2O_3. it has been observed that TiC/TiCN/TiN coatd cutting tool gave lower cutting forces than TiCN/TiC/Al_2O_3 coated ones. It is due to the top layer coating TiN have low coefficient of friction on the tool rake face than Al_2O_3 coating which reduce adhesion of the workpiece material to the cutting tool rake face as a result, tol chip contact length on the tool rake face decreases and thus, reduces the force developed.

2.4 OBJECTIVE OF THE EXPERIMENT:

From the literature review it has been observed that some research work was undertaken to study the performance of multilayer coated tool while machining austenitic stainless steel, still there exist some gaps which need to be researched in more details. There is no systematic report on study of performance of multilayer coating tool with respect to the machining parameters on on tool life and various chip characteristics of 316 austenitic stainless steel .keeping this in mind, the objective of the present work has been processed as follows

1. To study the performance of multilayer coated tool inserts during machining of austenitic stainless steel.
2. To study the effect of cutting speed on average flank wear for different duration of machining at constant feed and depth of cut.
3. To study the influence of cutting speed on various chip characteristics during dry machining of austenitic stainless steel. The different chip characteristics include types and clour of chip , macro morphology of chip, and chip thickness.

CHAPTER 3

EXPERIMENTAL METHODS AND CONDITIONS

3.1 SETUP FOR TURNING STATE

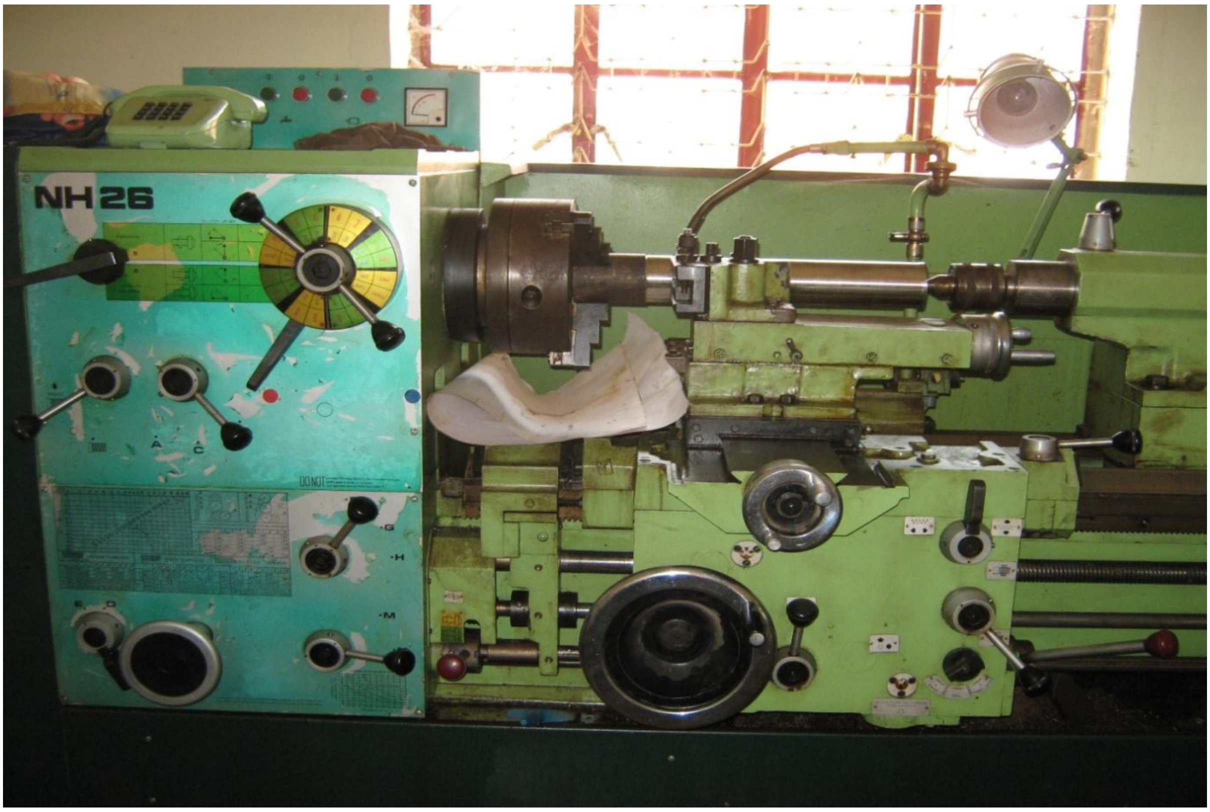


Figure 1 HMT LATHE MACHINE

Fig. 1 shows the HMT NH2 LATHE MACHINE through which turning test were carried out for testing purposes. The lathe applied in experiments is powered by 2.2 kW .Turning tests were carried out for testing tool wear of single point turning tools. Tool wear was measured by using optical microscope and scanning electron microscope (SEM). The experiment was carried out at three different cutting speeds (100M/MIN, 150M/MIN, 200M/MIN), and a constant feed rate and depth of cut of (0.2mm/rev) and (1mm) respectively.

3.2 DESCRIPTION OF CUTTING TOOL.

The substrate used in this experiment is ISO P30 cemented carbide over that multilayer coating of 10 micron was deposited using moderate temperature chemical deposition technique. The layer sequence of the multilayer coating is TiN-TiCN-Al2O3-ZrCN. This multilayer coating has been selected for good balance of wear resistance and toughness properties which is essential for machining austenitic stainless steel. ZrCN film top layer proved to have high hardness, high chemical and thermal stability, good tribological and corrosion behaviour for effective protective coatings against wear, abrasion and corrosion.

TABLE.3.1 COMPOSITION OF P30 GRADE

GRADE	**WC**	**Co**	**Ti+ TaNbC**	**Density**	**Hardness Rockwell**	**Hardness Vickers**	**T.S.R**	**Particle size**
Unit	**%**	**%**	**%**	**g/cm^3**	**HRA**	**HV30**	**N/mm^2**	μ m
P30	74	11	15	12.4	89.5	1420	2400	2.5

<u>TOOL DESIGNATION</u>

The tool designation for P30 grade is SCMT 12 04 08.The S stands for square(insert shape) i.e. 90^0 , C stands for clearance angle which is 7^0 , M stands for medium tolerance which is ±0.005”(thickness), T stands for insert features i.e. counter sinking hole with chip groove on top surface, 12 means length of each cutting edge is 12 mm, 04 stands for nominal thickness of the insert i.e. 4mm, 08 stands for nose radius which is 0.8mm.

<u>TOOL HOLDER DESIGNATION</u>

ISO SSBR 2020K12 (Kennametal, India)

3.3 WORKPIECE DETAILS

AISI 316 Austenitic stainless steel of 600mm long and 80mm diameter were used for the dry turning experiment in the present study. Grade 316 is the standard molybdenum-bearing grade. The molybdenum gives 316 better overall corrosion resistant properties than Grade 304, particularly higher resistance to the pitting and crevice corrosion in chloride environments. It also has excellent forming and welding characteristics. It is readily brake or roll formed into a variety of parts for the applications in industrial, architectural, and transportation fields. Grade 316 also has an outstanding welding characteristic. Post-weld annealing is not required when welding with thin sections. Grade 316L, the low carbon version of 316 type and is immune from the sensitisation (grain boundary carbide precipitation). Thus it is extensively used in heavy gauge welded components (over about 6mm). Grade 316H, with its higher carbon content has application at the elevated temperatures, as does stabilised grade 316Ti.

Table .3.2 Composition ranges for 316 grade of stainless steels.

Grade		C	Mn	Si	P	S	Cr	Mo	Ni	N
316	Min	-	-	-	0	-	16.0	2.00	10.0	-
	Max	0.08	2.0	0.75	0.045	0.03	18.0	3.00	14.0	0.10
316L	Min	-	-	-	-	-	16.0	2.00	10.0	-
	Max	0.03	2.0	0.75	0.045	0.03	18.0	3.00	14.0	0.10
316H	Min	0.04	0.04	0	-	-	16.0	2.00	10.0	-
	max	0.10	0.10	0.75	0.045	0.03	18.0	3.00	14.0	-

3.4 EXPERIMENTAL DETAILS

Cutting parameters for the dry turning tests of AISI 316 austenitic stainless steel material were selected to achive appropriate tool life. Tool wear criteria were the value of flank wear width of VB = 0.3mm or VB_{max} = 0.6mm. Cutting speeds in turning test were V_c = =100, 150 and 200 m/min, feed rate = 0.2mm/rev and depth of cut = 0.1mm. After machining for 60 second the tool material was cleaned with the help of aqua 20% H_2SO_4 and then through acetone. Then the sample was viewed under stereo zoom optical microscope. Average flank wear (VB) was measured using image analiser software (calipro) and photograph of flank and rake surface was also taken. Then the turning was continued for another 60s with same cutting edge and machining parameters and again it was cleaned and the process was repeated till the average flank wear reached the value of 0.3mm. If the tool life is finished, a fresh cutting edge of same insert was used for V_c=150m/min and thus, it was continued for V_c= 200m/min. In this way the influence of tool wear with different machining duration for different cutting velocity of 100, 150 and 200 m/min was studied.

Other than tool wear, chip morphology was also been studied. Chip was collected for each turning trail. Macro morphology of chip was studied using digital camera, stereo zoom optical microscope and also studied using SEM. Chip thickness were measured using digital vernier calliper and optical microscope coupled with image analiser respectively.

CHAPTER 4

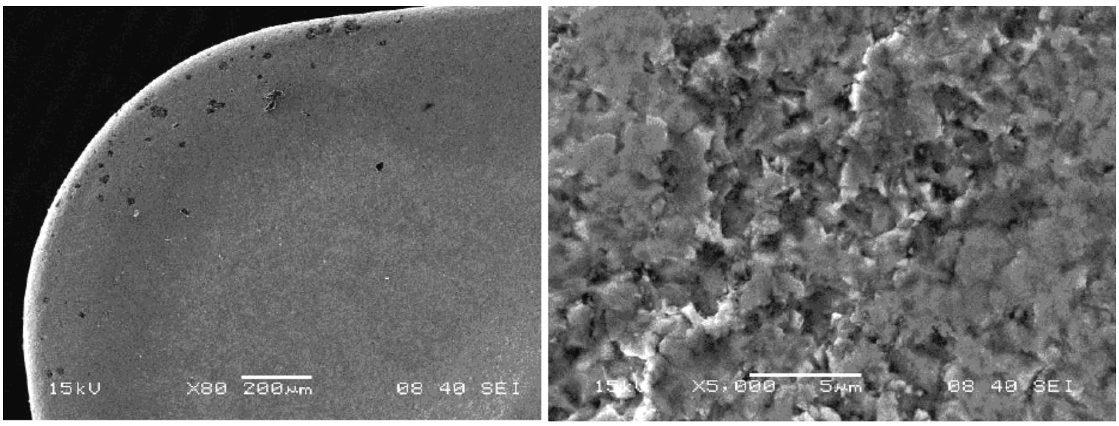
RESULTS AND DISCUSSION

.

4.1 CONDITION OF COATED TOOL BEFORE MACHINING :

a b c

Figure 4.1 optical microscope images of (a) Flank surface (b) Rake face (c) top view of coated carbide insert.

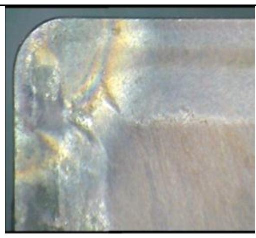
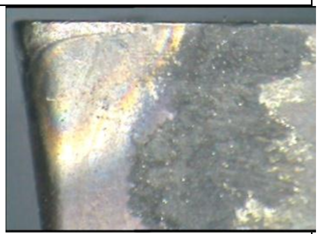
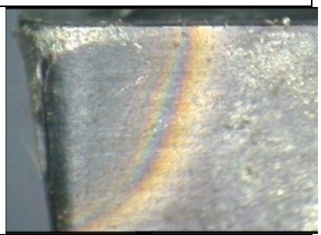
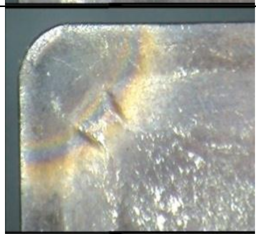
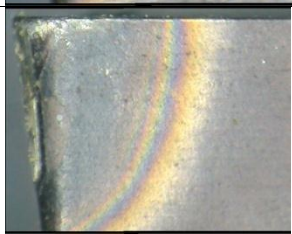
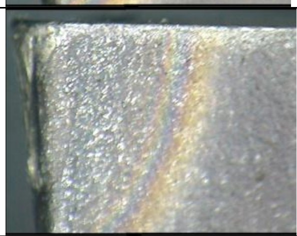
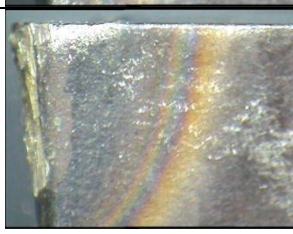
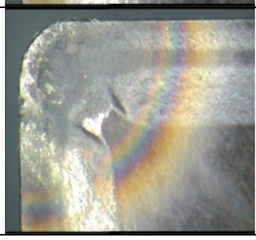
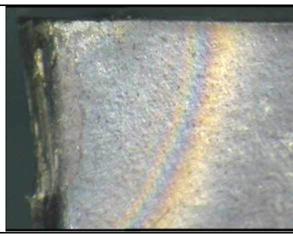


a b

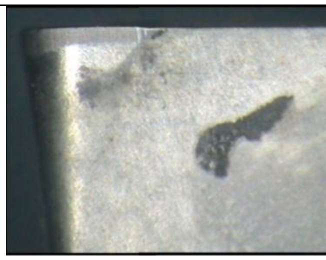
Figure 4.2 SEM image of rake face with magnification (a) 80X (b) 5000X

4.2 TOOL WEAR

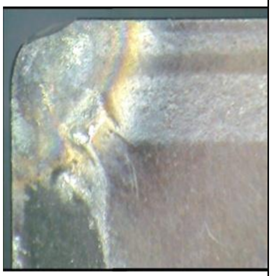
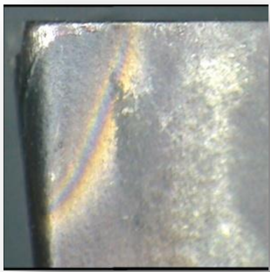
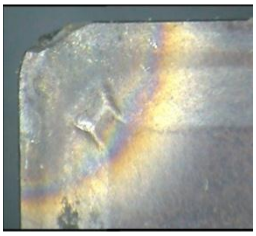
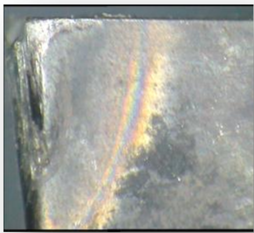
Fig. 4.3 Shows the condition of the rake and flank surface of the multilayer coated tool after machining AISI 316 austenitic stainless steel with different machining duration for different cutting speed (i.e. V_c = 100, 150 and 200 m/min). It is evident from the fig. that the condition of the rake surface was not adversely affected as the turning operation progressed for different cutting speed. However, there was evidence of chipping at nose of the tool insert when machining was carried out at V_c = 200 m/min. The fig. also shows the progression of flank wear for different cutting speed and it clearly demonstrated that the cutting speed has significant influence on flank wear while dry machining of 316 austenitic stainless steel. The progression of flank wear for different cutting speed has also been graphically represented in fig. . It is depicted from both fig 4.3 (a) and (b) that as cutting speed increased the average flank wear also increased and the increase is more predominant at V_c = 200 m/min. The adverse flank wear condition and the chipping of the nose may be attributed due to the work hardening tendency and low thermal conductivity characteristics of the austenitic stainless steel. Therefore, it may be concluded that it is not recommended to machine 316 austenitic stainless steel under dry condition with a cutting speed of 200m/min.

V_c=100 m/min , f=0.2mm/rev, t=1mm			
SL.NO.	MACHINING DURATION (sec)	RAKE SURFACE	FLANK SURFACE
1	120		
2	240		
3	300		
4	420		
5	480		
6	540		
7	600		

(a)

V_c=150 m/min , f=0.2mm/rev, t=1mm			
SL.No.	MACHINING DURATION (Second)	RAKE SURFACE	FLANK SURFACE
1	120		
2	240		
3	360		

(b)

V_c= 200 m/min ,f=0.2mm/rev,t=1mm			
SL.NO.	MACHINING DURATION	RAKE SURFACE	FLANK SURFACE
1	60s		
2	120s		
3	180s		

(c)

Figure 4.3 : optical microscope images of rake and flank surface of the multilayer coated carbide insert after machining S316 with different cutting speed (a) V_c =100m/min (b) V_c = 150 m/min (c) V_c = 200 m/min

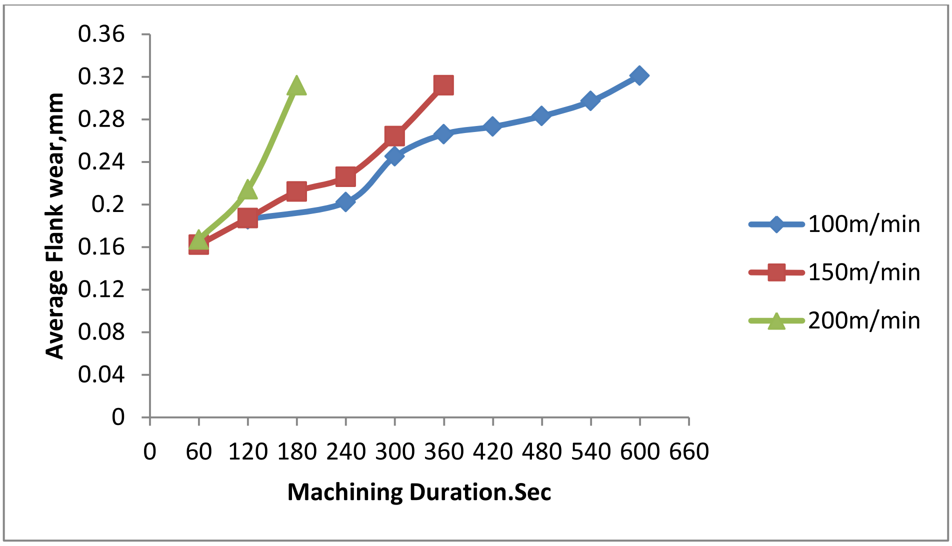


Fig.4.4 Variation of average flank wear with machining duration for different cutting speeds during machining of SS316

4.2 CHIP FORMATION

Table 4.1 chip morphology

V_c m/min	Types of chips	Colour of the chip	Chip thickness mm
100	Continous	yellow	0.435
150	Continous	yellow	0.353
200	Continous	yellow	0.323

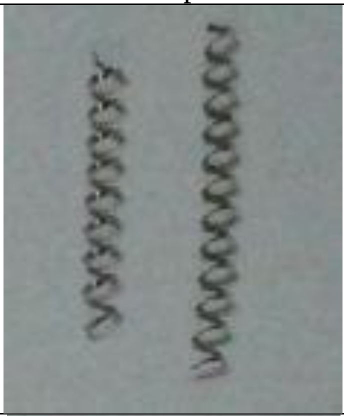
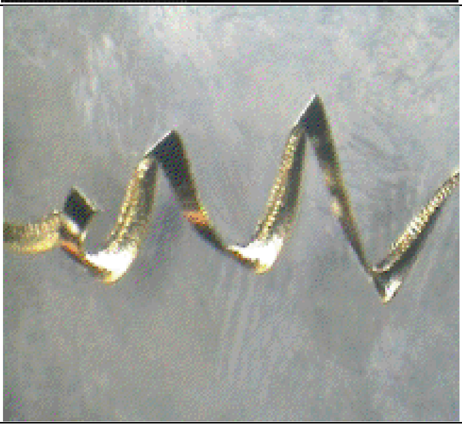
Cutting speed(V_c) m/min	Optical macroscope image	Macro morphology of the chip
100		
150		
200		

Figure 4.5 optical images of chip at different cutting speed

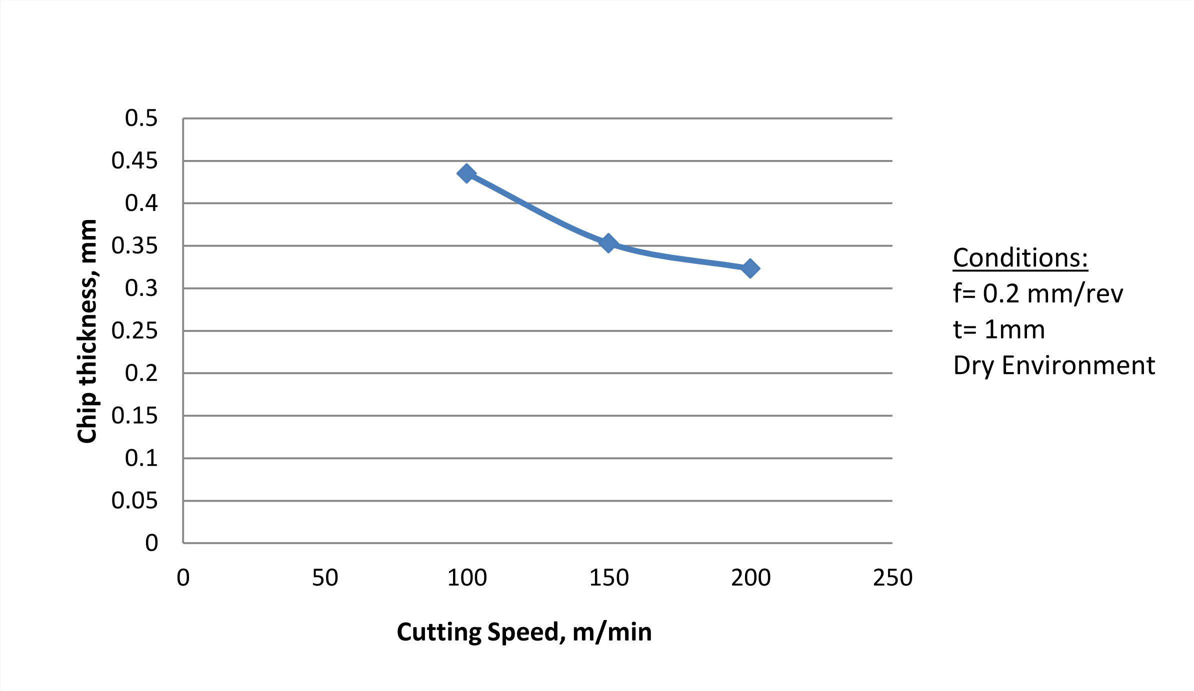


Figure 4.6 variation of chip thickness with respect to cutting speed

Table 4.1 shows the types of chip formation (continuous or discontinuous), colour and thickness of the chip formed. Fig. 4.6 shows the chip thickness curve in the dry machining of AISI 316 austenitic stainless steel at cutting speed of 100, 150 and 200 m/min, feed rate of 0.2mm/rev and depth of cut of 1mm. Average chip thickness for different duration of 60, 120 and 180 sec has been measured. Chip thickness were founded t be related to the cutting speed at which machining tests were performed. It is evident from the fig. that low cutting speed led to big chip thickness while increasing cutting speed chip thickness decreases. Chip thickness can be related to shear plane angle, if there is big chip thickness, the shear plane angle become small and the chips move slowly on the rake face of the tool. Due to which lower shear plane angle also requires more energy to deform the work piece material and it increases heat and cutting forces and this, increases vibration.

CHAPTER 5

CONCLUSION:

From the present investigation the following conclusions may be drawn

1) The multilayer coating TiN-$TiCN$-Al_20_3-$ZrCN$ has a strong potential in dry machining of AISI 316 grade austenitic stainless steel.
2) The effect of cutting speed on tool wear was found to be significant. The average flank wear while machining with V_c = 100 m/min after a particular machining duration was found to be minimum compared to those for V_c= 150 and 200 m/min. however increase of average flank wear for V_c = 150 m/min was not much.
3) The tool life for V_c = 100,150 and 200 m/min was found to be 600s, 360s, and 180s respectively.
4) The cutting speed was also found to influence different chip thickness. As cutting speed increased chip thickness (as observed from macro morphology of the chip) decreases.

REFERENCES:

Ciftci,I.; Machining of austenitic stainless steels using CVD multi-layer coated cemented carbide tools. Tribology International 39 (2006) 565–569

Korkut,I.; Kasap, M.; Ciftci,I.; Seker, U.; Determination of optimum cutting parameters during machining of AISI 304 austenitic stainless steel; Materials and Design 25 (2004) 303–305

Ezugwu, E. O. , Olajire, K. A. and Jawaid, A.(2001) 'WEAR PERFORMANCE OF MULTILAYERCOATED CARBIDE TOOLS', Machining Science and Technology, 5: 1, 115 — 129

Jindal, P.C.; Santhanam, A.T.; Schleinkofer, U.; Shuster, A.F.; Performance of PVD TiN, TiCN, and TiAlN coated cemented carbide tools in turning. International Journal of Refractory Metals & Hard Materials 17 (1999) 163±170.

Selvaraj D.P. , Chandramohan P. , Influence of Cutting Speed, Feed Rate and Bulk Texture on the Surface Finish of Nitrogen Alloyed Duplex Stainless Steels during Dry Turning. *Engineering*, 2010, 2, 453-460

Gutakovskis, V.; Bunga, G.; & Torims, T; STAINLESS STEEL MACHINING WITH NANOCOATED DURATOMICTM CUTTING TOOLS; INDUSTRIAL ENGINEERING" 22-24 April 2010, Tallinn, Estonia

Paro, J.; Hanninen, H.; Kauppinen, V.; Tool wear and machinability of X5 CrMnN 18 18 stainless steels. Journal of materials processing technology 119 (2001) 14-20.

Lin, T.R.; Cutting behavior of a TiN-coated carbide drill with curved cutting edges during the high-speed machining of stainless steel. Journal of Materials Processing Technology 127 (2002) 8–16.

Knutsson, A. ; Johansson, M.P. ; Karlsson, L.; Odén, M.; Machining performance and decomposition of TiAlN/TiN multilayer coated metal cutting inserts. Surface & Coatings Technology 205 (2011) 4005–4010.

Selinder, T.I.; Sjostrand, M.E.; Nordin, M. Larsson, M. ;. Ostlund a, A.; Hogmark, S. ; Performance of PVD TiN/TaN and TiN/NbN superlattice coated cemented carbide tools in stainless steel machining. Surface and Coatings Technology 105 (1998) 51–55.

Orrego, D.A.F; Jimenez, L.B.V.; Atehortua, J.D.E; Ochoa, D.M.L; Effect of the variation of cutting parameters in surface integrity in turning processing of an AISI 304 austenitic stainless steel. TriboBr-2010.

DeGarmo EP, Black JT, Kohser RA. Materials and processes in manufacturing. New Jersey: Prentice-Hall Inc.; 1997.

Sarwar M, Zhang X, Gillibrand D. Performance of titanium nitridecoated carbide tipped circular saws when cutting stainless steel and mild steel. Surf Coat Technol 1997;94–95:617–21.

Groover MP. Fundamentals of modern manufacturing—materials, processes and systems. New Jersey: Prentice-Hall Inc.; 1996.

Lanjewar, R>W.; Saha, P.; Dutta, U.; Banerjee, A.J; Jain, S.; Sen, S.; Evaluation of machining parameters for the turning of AISI 304 austenitic stainless steel on auto sharpening machine. Journal of scientific & industrial research, Vol. 67, April 2008, pp. 2282-287

Jiang L, Roos A, Liu P. The influence of austenite grain size and its distribution on chip deformation and tool life during machining of AISI 304L, Metall. Mater. Trans. 1997; 28A: pp. 2415–22.

O_Sullivan D, Cotterell M. Machinability of austenitic stainless steel SS303. J Mater Process Technol 2002;124:153–9.

Cho, S.S.; Komvopoulos, K. ‘‘Wear mechanisms of multi-layer coated cemented carbide cutting tools,’’ *Journal of Tribology (Trans ASME)*, 119 (1997) 8–17.

Prengel HG, Santhanam AT, Penich RM, Jindal PC, Wendt KH. Advanced PVD-TiAlN coatings on carbide and cermet cutting tools. Surf Coat Technol 1995;94–95:597–602.

Agrawal, S.; Chakrabarti, A.K.**;** Chattopadhyay, A.B.; A study of the machining of cast austenitic stainless-steels with carbide tools**.** Journal of Materials Processing Technology 52 (1995) 610 620.